CHAPTER 3

DISCHARGE CHARACTERISTICS OF THE PLANAR COIL INDUCTIVELY COUPLED PLASMA SYSTEM

3.1 Introduction

In an inductively coupled plasma, two different modes of plasma exist. The first mode is called an E mode discharge, also known as the first stage of discharge [48]. This discharge occurs at low power operation. The second stage of discharge is called H mode discharge, operated at relatively high power. The transition between these two stages exhibits hysteresis behavior [43,49].

In planar coil configuration, cylindrical coordinate system is used with the origin at the center of the coil and the positive z pointing away from the coil on the plasma side while r is the radial coordinate. This configuration is shown in Figure 3.1. When the coil is powered by an RF source, the RF current will pass through the coil generating electromagnetic field, thus forming plasma.

The discharge is based on inductive coupled transformer model with the ratio of primary to secondary transformer of 7 : 1. In this section, the transitions from E to H mode in different argon/nitrogen gas admixture are observed. The bias currents of the substrate at different bias voltages in different argon/nitrogen admixture are measured.

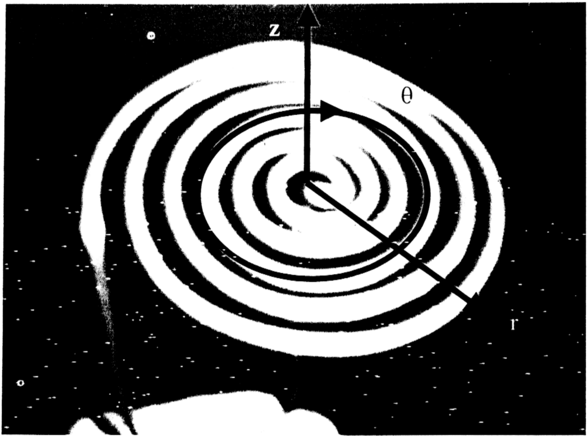

Figure 3.1: The cylindrical coordinates of the planar coil configuration.

3.2 Electrical Characteristics

E to H mode transition of the system for different argon/nitrogen mixtures is investigated. The coil currents corresponding to different RF powers applied are measured.

In the experiment, the variable capacitor is tuned for the E mode discharge so that the reflected power is minimum. The RF power is increased gradually until it reaches the H mode region. The power applied and the coil current is recorded. In the first experiment, only argon gas at 0.015 mbar (0 % Nitrogen) is used. The coil current is plotted against RF power applied, and the graph is shown in Figure 3.2.

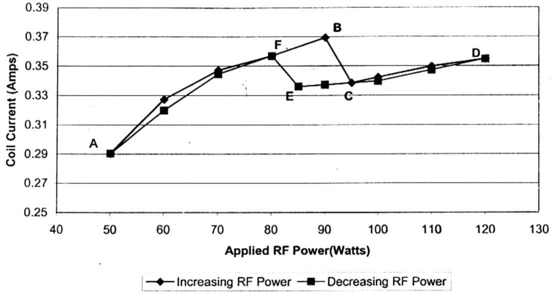

Figure 3.2: Coil current in argon plasma at 0.015 mbar (0% nitrogen).

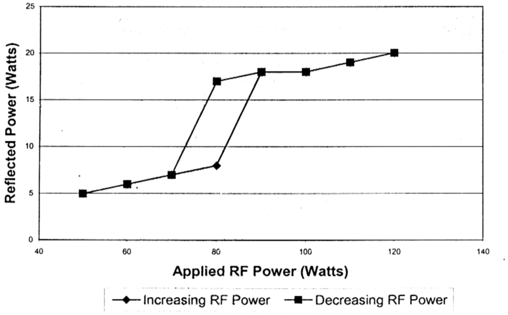

Figure 3.3: Applied and reflected RF power of planar coil ICP in argon plasma at 0.0015 mbar (0% Nitrogen).

As can be seen from Figure 3.2, the coil current increases with the increase of RF power, from A to B. This the E mode region. When the RF power reaches B, increasing the RF power see a sudden decrease of coil current, as illustrated by B to C. At this point, plasma emission luminosity is observed to increase suddenly due to electrical breakdown in the azimuthal direction. This gives rise to the onset of the H mode discharge. When the H mode occurs, plasma resistance increases, tuning is no longer possible and the reflected power becomes higher. This occurrence can be observed in Figure 3.3. Increasing the RF power further (from C to D) sees only a minimal increase of the coil current. Decreasing the RF power from D sees only minimal decrease of the of coil current. Upon reaching the critical point of E, there is a sudden jump in the coil current value to point F because the toroidal current has stopped. There is also a sudden decrease in plasma emission indicating the E mode operating regime. It is observed that the RF power at which H mode transition occurs during forward scan (increasing power gradually) that when it reverts back to the E mode regime (by decreasing power gradually).

The same procedure is repeated in the second experiment. In this experiment argon pressure is maintained at 0.015 mbar, but nitrogen gas is added into the chamber until the pressure reaches 0.05 mbar. The result of this experiment is shown in Figure 3.4.

It can be seen that by introducing nitrogen into the chamber, more power is required for the E to H mode transition as compared to argon at 0.015 mbar (70 % nitrogen). In argon only environment (at 0.015 mbar), the required power to achieve the H mode is around 80 Watts and the discharge reverts back to the E mode at 70 Watts. In argon/nitrogen environment at 0.05 mbar, around 240 Watts is required. When the power decreased gradually, the discharge reverts back to the E mode at around 230 Watts. More nitrogen is added until the pressure reaches 0.1 mbar (85 % nitrogen), 0.15 mbar (90 % nitrogen) and 0.2 mbar (92.5% nitrogen). Table 3.1 show the applied RF power required to obtain the H mode discharge and to revert back to the E mode discharge at different pressures and argon/nitrogen compositions.

PRESSURE (mbar)	NITROGEN PERCENTAGE	E to H mode transition point	H to E mode transition point
0.015	0	80 Watts	70 Watts
0.05	70	240 Watts	230 Watts
0.10	85	420 Watts	380 Watts
0.15	90	470 Watts	390 Watts
0.20	92.5	500 Watts	400 Watts

Table 3.1: RF power required to obtained E and H mode discharges at different pressures and argon/nitrogen compositions.

For argon/nitrogen admixture at 0.25 mbar (99.4 % nitrogen), the RF power required for H mode discharge is above the maximum capacity of 550W of the RF generator. The power required for E-H mode and H-E mode transition is summarized in Figure 3.8.

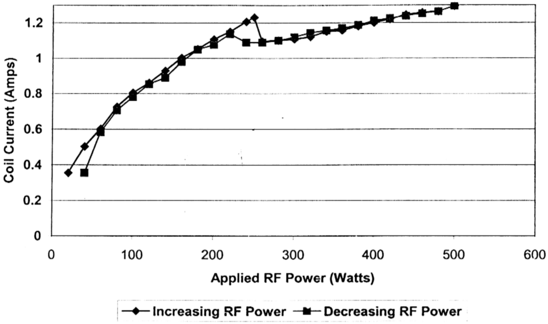

Figure 3.4: Coil current in argon-nitrogen plasma at 0.05 mbar (70% Nitrogen).

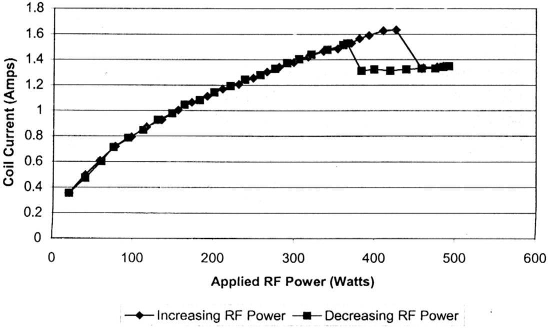

Figure 3.5: Coil current in argon-nitrogen plasma at 0.1 mbar (85% Nitrogen).

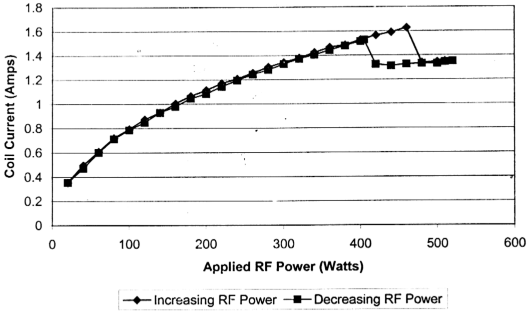

Figure 3.6: Coil current in argon-nitrogen plasma at 0.15 mbar.

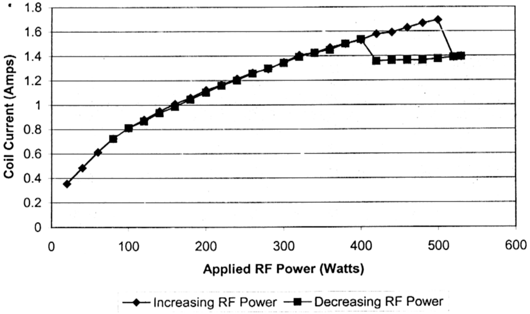

Figure 3.7: Coil current in argon-nitrogen plasma at 0.2 mbar.

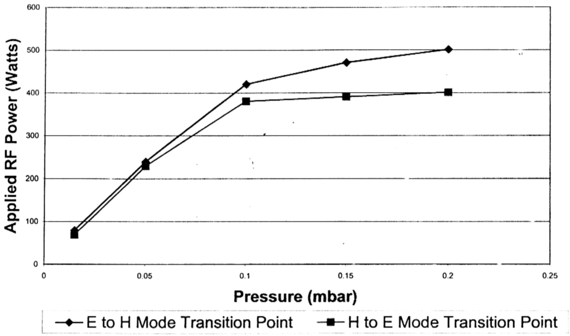

Figure 3.8: Minimum RF power required to obtain the H mode discharge at different pressure.

3.3 Optical emission spectroscopy

The optical emission spectral measurements are performed in the H mode regime. The RF power applied is maintained at 450 Watts for all experiments. The spectrometer dial reading is set at 825 and the exposure time is 0.1 second. The argon pressure is held at 0.015 mbar, and nitrogen is added to obtain a chamber pressure of 0.05, 0.1, 0.15 and 0.2 mbar respectively.

In the argon-nitrogen plasma the following reactions takes place:

For argon;

$e + Ar \rightarrow Ar^+ + 2e$ (reaction 1)

And for nitrogen, electron impact dissociation of molecular nitrogen will produce predominantly nitrogen atoms:

$e + N_2 \rightarrow 2N + e$ (reaction 2)

And also,

$e + N_2 \rightarrow 2e + N + N^+$ (reaction 3)

In plasma assisted nitriding process, reaction (2) should be dominant [50]. Because of this, measurement of nitrogen species is essentially related to nitrogen atoms.

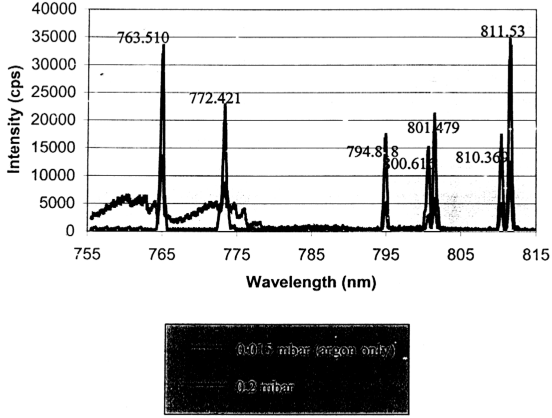

Figure 3.9: Spectrum obtained in argon and argon-nitrogen admixture at different pressure.

Figure 3.9 shows the results obtained in argon and argon-nitrogen admixture plasmas at 0.015 mbar and 0.2 mbar respectively. The Ar peaks identified are at 763.510, 772.421, 794.818, 800.616, 801.479, 810.369 and 811.530 nanometers respectively. Referring to Figure 3.10, it can be seen that by increasing the nitrogen content inside the chamber, the Ar at 772.421 nm intensity decreases. This may be due to the fact that at higher nitrogen pressure more power is absorbed by dissociation process of nitrogen molecules; hence less power is absorbed by argon for excitation. It is also observed that the 'shoulder' like shape is present when nitrogen is added into the chamber. This may be due to the presence of molecular nitrogen in the plasma.

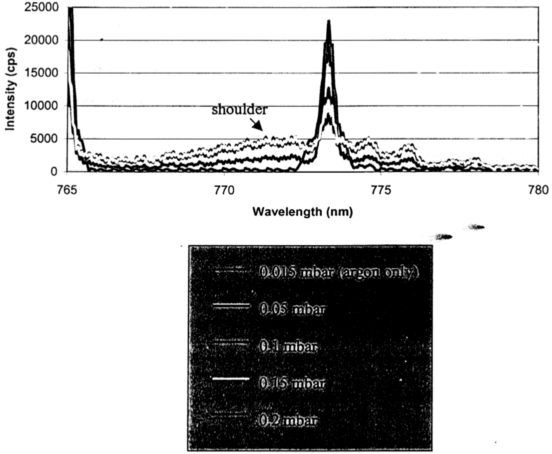

Figure 3.10: Comparison of Ar at 772.421 nm line intensity measured at different pressure in argon- nitrogen plasma.

3.4 Substrate current during biasing

In this experiment, the current is measured at different negative voltages, at chamber pressures of 0.05, 0.1,0.15 and 0.2 mbar, using the built in current meter in the bias power supply. The RF power applied to the system in all experiment is set at 450 W. The substrate used in this experiments is pure titanium with dimension of 2.5 cm x 2.5 cm x 0.75 cm. The result of this experiment is shown in Figure 3.11. It is observed that the highest current recorded is for the operation at the lowest pressure (0.05 mbar). Increasing the pressure sees the decrease of current density flowing through the substrate. This is due to the fact that at higher pressure, the electrons and ions have lower mean free path. Furthermore, at higher argon-nitrogen pressure, fewer electrons are produced as indicated by a fewer argon dissociations, hence less electrons are extracted from the plasma.

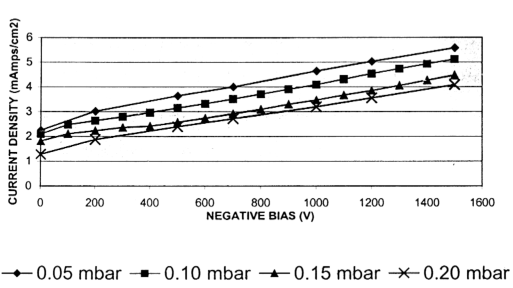

Figure 3.11: Substrate current density through biasing in argon-nitrogen plasma at different pressure.